Development of Switch Mode Dc Converter Using MATLAB/ dSPACE

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***Abstract*— In this paper with the help of Matlab/Simulink and dSPACE, the Switch-Mode DC Converter is built in real-time to control the output voltage of the controller using PWM algorithm. First, the Simulink model of Switch-Mode DC Converter (i.e. Single-Pole and Two-Pole Converter Model) is built and, after verifying the results, it is implemented in real-time. Next, a DC motor is connected to the output terminals (i.e. Phase A1 and Phase B1) of the Power Electronics Board such that a variable voltage is applied to the terminals of DC motor. Now, by changing the magnitude of the applied voltage, the speed of the motor is varied. This is also referred to as an open-loop voltage control of DC motor. The purpose of the real-time implementation is obtaining variable voltage at the output of the power converter, while controlling its amplitude with a dSPACE DS1104-based user interface.**

***Index Terms*—Single-pole, Two-pole, dSPACE.**

I. Introduction

In the switch pole converter circuit, the input voltage and output load are assumed constant. The switching power pole operates with a switching function $q_A(t)$, whose waveform repeats, unchanged from one cycle to the next, and the corresponding switching duty ratios are constant at its DC steady-state. The output pole voltage $V_{AB}(t)$ is either V_d (input voltage) or 0 depending upon the position of the converter switch. The converter switch is pulse-width modulated by comparing triangular waveform with the control voltage V_c. There are two such PWM strategies, one is PWM with unipolar voltage switching in this, switches in each leg are controlled independently of the other leg and another one is PWM with bipolar voltage switching, in this, switches in each pair are turned ON and OFF simultaneously. The objective is to develop a real time model using dSPACE DS1104_DSP_PWM3 to obtain variable voltage at the output of the converter for controlling speed of the DC motor. The dSPACE provides complete solutions for electronic control unit (ECU) software development and it is powerful development tools for dedicated services in the field of function prototyping, target implementation, and ECU testing. Real time control systems can be built using dSPACE and the control logic can be implemented and works on Matlab/ Simulink platform. Here the speed of the DC motor is controlled by Pulse Width Modulation (PWM) technique to obtain a smooth speed variation without reducing the starting torque of the motor.

II. PWM techniques of power pole converter

Controlling the pulse width of the switching function $q_A(t)$ can be accomplished using a technique called Pulse Width Modulation (PWM). In this technique a control voltage $V_{C,A}(t)$ is compared with triangular waveform signal to obtain $q_A(t)$.

$$\text{if } V_{C,A}(t) > V_{tri}(t) \Rightarrow q_A(t) = 1$$
$$\text{if } V_{C,A}(t) < V_{tri}(t) \Rightarrow q_A(t) = 0$$

The average output voltage $V_{AN}(t)$ of the power-pole with respect to duty ratio over one switching cycle is given by

$$V_{AN}(t) = q_A(t)*V_d$$

A.PWM with unipolar voltage switching

The uni-polar switching converter [4] shown in fig.1 consists of single pole. The output pole-voltage, $V_{AB}(t)$ of the unipolar converter is either V_d (input voltage) or 0, depending upon the position of the bi-positional switch and the pole switching function $q_A(t)$.

The duty ratio for a single PWM pole is given by the equation.

$$d_A(t) = \frac{1}{2} + \frac{1}{2}\frac{v_{c,A}(t)}{\hat{V}_{tri}}$$

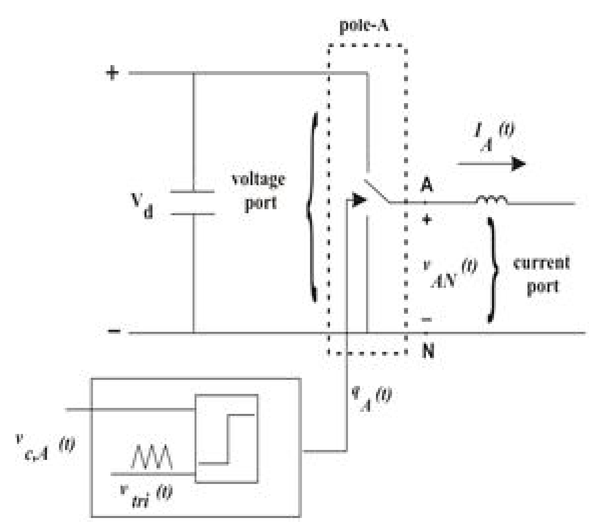

Figure 1. Single-pole converter

DOI: 01.IJCSI.02.03.197

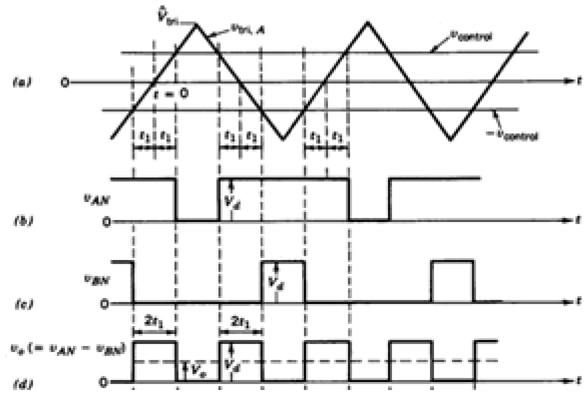

Figure 2. Unipolar voltage switching

For V_{tri} = 1V we obtain the relation for the control voltage $V_{C,A}(t)$.

$$v_{c,A}(t) = \frac{2\bar{v}_{AN}(t)}{V_d} - 1$$

B. PWM with bipolar voltage switching

In two pole converter model [4], the average output voltage $V_o(t)$ can be positive or negative. The DC converter consists of two switching power poles as shown in Fig. 3.

The converter average output voltage is the difference between the two pole output voltages, measured with respect to the DC bus ground.

$$V_o(t) = V_{AB}(t) = V_{AN}(t) - V_{BN}(t)$$

The output voltage $V_{AB}(t)$ as shown in fig 4. At any given instant of time, the control voltages for the two poles are complimentary, i.e.

$$v_{c,A}(t) = -v_{c,B}(t) = \frac{\bar{v}_{AB}(t)}{V_d}$$

$$d_A(t) = \frac{1}{2}\left(v_{c,A}(t) + 1\right)$$

$$d_B(t) = \frac{1}{2}\left(-v_{c,A}(t) + 1\right)$$

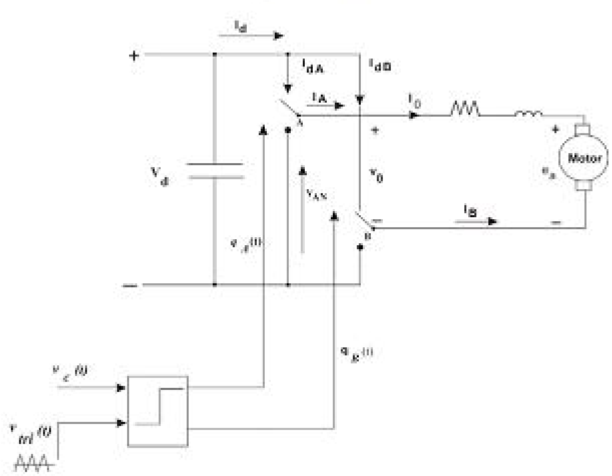

Figure 3. Two-pole DC converter

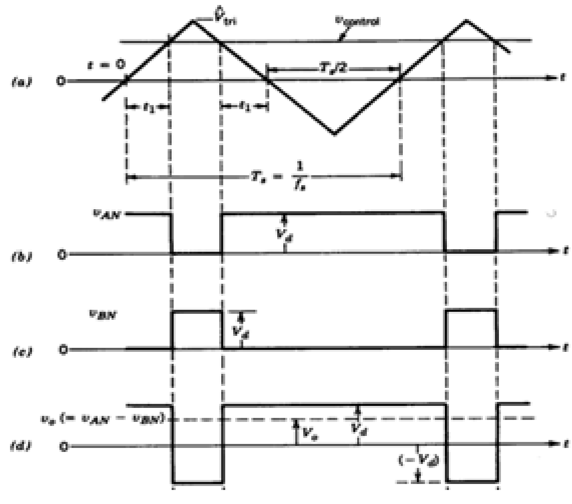

Figure 4. Bipolar voltage switching

II. Simulation Of Dc Switch Mode Converter

A. Simulink Model for Single Pole Converter

The simulink model is implemented to obtain the duty ratio and switching function for the single pole converter model shown in Fig 5. The control voltage $_{C,A}(t)$ is compared with triangular waveform using a relay block. The output of relay is set to 1 if the difference between control voltage and triangular signal is positive, otherwise 0. The values of DC bus voltage (V_d = 42) and switching frequency (fsw = 10000) are set at the Matlab command prompt before the simulation. The desired voltage V_{AN}, with respect to the negative dc-bus ground is set by a constant block with the value of one, and can be varied with a slider gain from '0' to the maximum dc-bus voltage V_d (42V). The duty ratio and switching function waveforms of single-pole converter model are shown in Fig. 6.

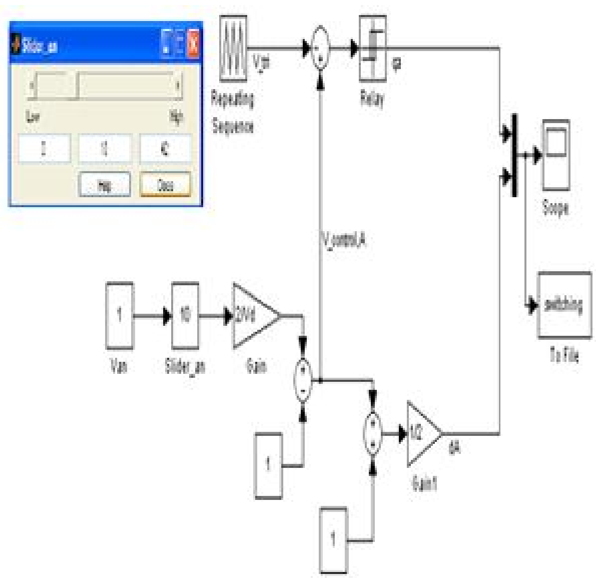

Figure 5. Simulink model of switching function and duty ratio generation of single pole converter

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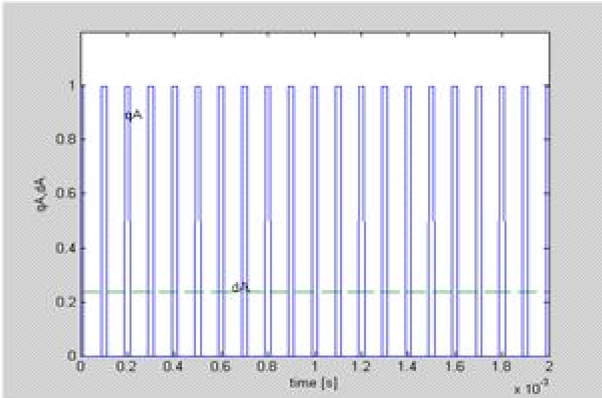

Figure 6. Switching function qA and duty ratio q_A

B. Simulink Model for two - Pole Converter

Simulink model of two pole converter in Fig. 7 is the comparison of two control voltages $V_{C,A}(t)$ and $V_{C,B}(t)$ with triangular waveform. The Switch block, which allow the upper signal to pass when the middle input is greater than the specified threshold and the lower signal in the opposite case. The Relay block provides the switching functions for the poles q_A and q_B. The converter output voltage will be the difference between the two pole-output voltages, measured with respect to the dc-bus ground In the two-pole converter model the output voltage is determined with two slider gain values. Fig. 8 presents the output voltage and duty ratios when the slider gain was set to positive value. In the Fig. 9 the output voltage and duty ratios are calculated when the slider gain value was set to negative value. The input is the desired average output-voltage V_{AB}. The instantaneous output voltage will be a square wave signal and the average value will be equal to the value set by slider gain. By varying the value of slider gain (i.e. vary the desired average output voltage value), the output voltage value changes.

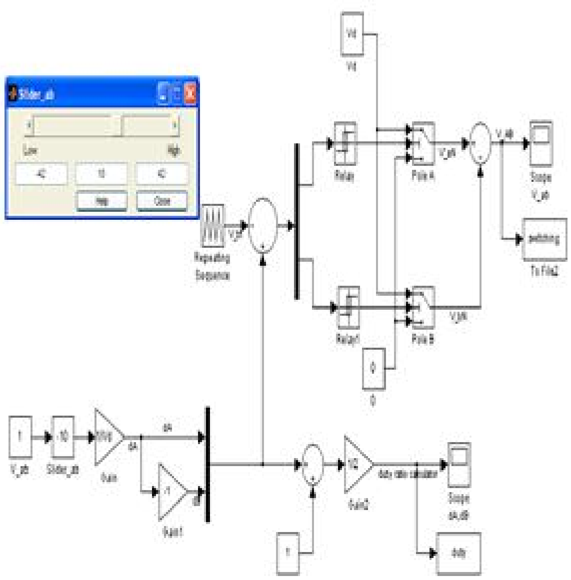

Figure 7. Simulink model of switching function and duty ratio generation of two pole converter

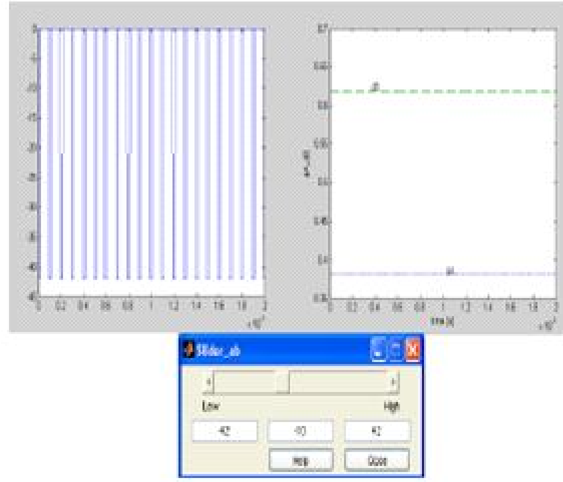

Figure 8. Two-pole converter model with Vout = +10v

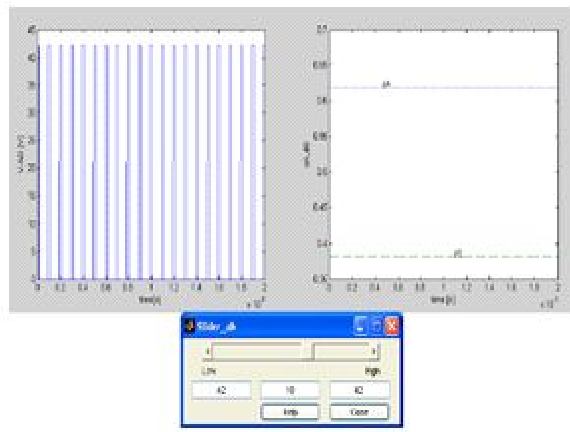

Figure. 9 Two-pole converter model with Vout = -10V

C. Simulink model for Real time two pole Switch mode converter

After obtaining the results of duty ratios and output voltage for the two-pole converter in the Simulink, this converter is implemented in the real-time on dSPACE DS1104 controller board. In the real-time model the converter output voltage can be controlled with the help of dSPACE control – desk.

The triangular waveform generator and the comparator for all converter poles of Fig 7 can be replaced with DS1104SL_DSP_PWM3 [2] block provides by dSPACE. The duty ratios served as the inputs to DS1104SL_ DSP_PWM3. The Fig. 10 presents the two – pole converter model in real–time.

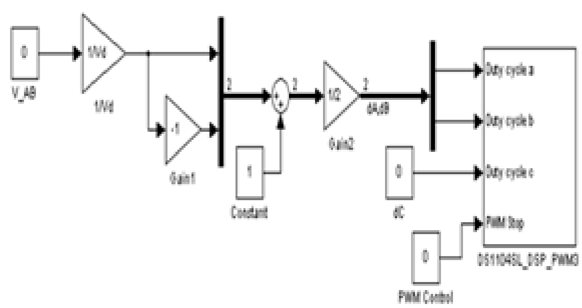

Figure 10. Two Pole Switch-Mode Converter Model in Simulink

DOI: 01.IJCSI.02.03.197

IV. Implementation of switch mode DC converters in DC motor

The implementation of the model for control of DC Motor in open-loop as shown in Fig. 11. The DC motor is connected to the output terminals of the Power Electronics Board such that a variable voltage is applied to the terminals of DC motor. Now, by varying the magnitude of the applied voltage, the speed of the motor is varied. This is also referred to as an open-loop voltage control of DC motor. The set up has 42 V dc-bus, two completely independent 3-phase PWM inverters for complete simultaneous control of two DC machines, digital PWM input channels for real-time digital control of converters, and complete digital/analog interface with dSPACE board. Connect the armature of the dc-motor board has to be connected to Channel 5 A/D converter of the dSPACE controller box. The DS1104ENC_POS_C1 and DS1104ADC_C5 blocks of dSPACE library are used to measure the speed and current of the DC motor under control in real-time. Also, the encoder output is connected to the INC1 9-pins DSUB connector on the dSPACE controller. The speed of a dc-motor can be modified by varying its supply voltage. Connect the Lab Oscilloscope to the PHASE A1 and PHASE B1 terminals of the motor drives board.

A. Current measurement

For measuring the current we will be using Channel 5 of the A/D converter in the CP1104 control board [6]. The motor drives current sensor 1V equals 2 amps so it actually needs to be scaled by 20. The real-time value of armature current I_a for the supply voltage V_{AB} = 40V observed in the Control Desk window is shown in Fig. 12.

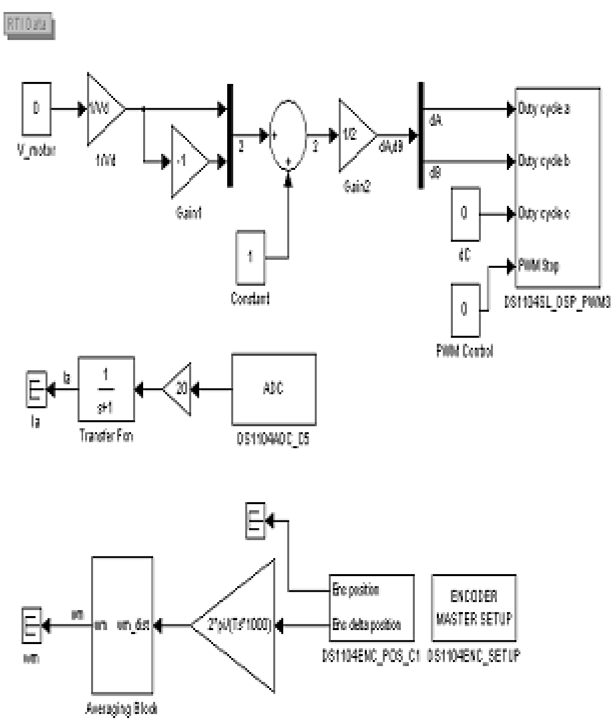

Figure 11. Real-time model for no-load motor test

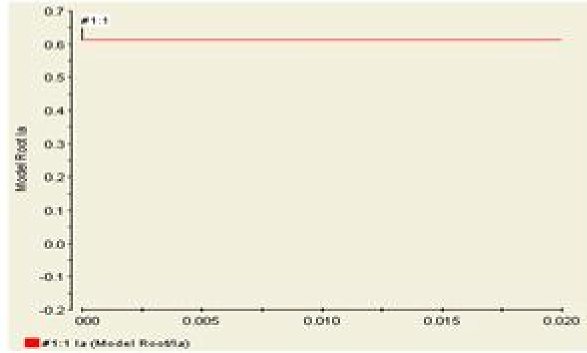

Figure 12. Armature Current at V_d = 40 V Displayed in the control desk

B. Speed Measurement

To measure speed of the dc motor use the DS1104ENC_POS_C1 [2], which provides read access to the delta position and position of the first encoder interface input channel. The delta position represents the scaled difference of two successive position values of a channel. To receive the radian angle from the encoder the result has to be multiplied with 2π/ encoder lines (1000). At low speeds, it was observed some oscillations in average speed in order to improve the overall accuracy 11 point averaging block is constructed as shown in Fig. 13. The speed of the dc motor is measured and displayed in the control desk shown in Fig. 14. The voltage vs. speed characteristic of DC motor for different voltages at no-load is measured and verified theoretically as shown in Fig. 15.

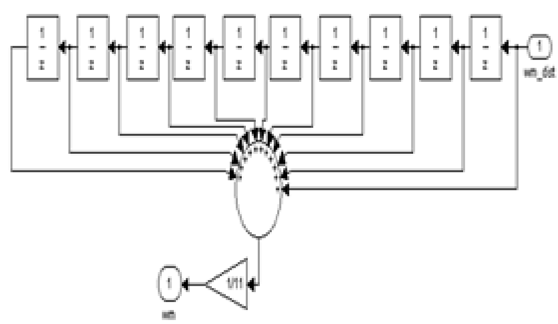

Figure 13. Averaging model in Simulink

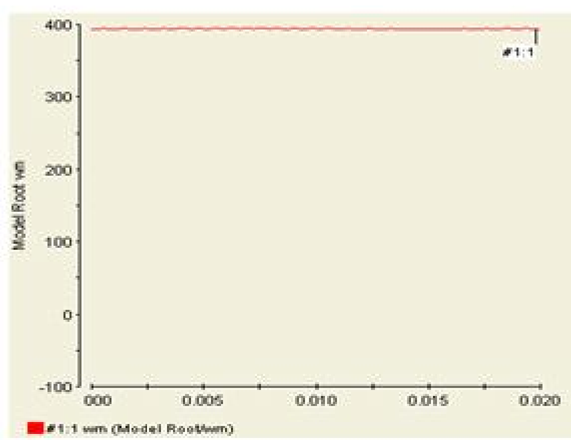

Figure 14. Speed of dc motor at V_d = 40V displayed in the control desk

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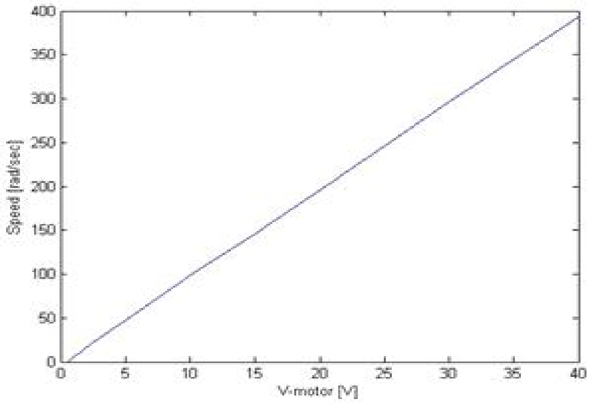

Figure 15. Voltage vs. speed characteristics at no-load

Conclusion

In this paper, first, the single-pole and two-pole converter models are built and simulation results for the positive and negative values of slider gain are observed. Next, the comparator and the triangular waveform block of two-pole converter model is replaced with the DS1104SL_DSP_PWM3 block and the converter model is implemented in real-time. Finally, real-time model for speed control of DC motor is built and the voltage-speed characteristic of DC motor for different voltages at no-load is measured and verified theoretically.

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DOI: 01.IJCSI.02.03.197